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From the INTERNATIONAL BUREAU

PCT

NOTICE INFORMING THE APPLICANT OF THE COMMUNICATION OF THE INTERNATIONAL APPLICATION TO THE DESIGNATED OFFICES

(PCT Rule 47.1(c), first sentence)

To:

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Date of mailing *(day/month/year)*
22 January 2004 (22.01.2004)

- 4 FEB. 2004

Applicant's or agent's file reference
PHNL020667WO

IMPORTANT NOTICE

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/IB2003/002853	25 June 2003 (25.06.2003)	10 July 2002 (10.07.2002)

Applicant
KONINKLIJKE PHILIPS ELECTRONICS N.V. et al

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3. Enclosed with this notice is a copy of the international application as published by the International Bureau on 22 January 2004 (22.01.2004) under No. WO 2004/008441

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(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
22 January 2004 (22.01.2004)

PCT

(10) International Publication Number
WO 2004/008441 A2

(51) International Patent Classification[7]: G11B 7/00

(21) International Application Number: PCT/IB2003/002853

(22) International Filing Date: 25 June 2003 (25.06.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
02077782.7 10 July 2002 (10.07.2002) EP

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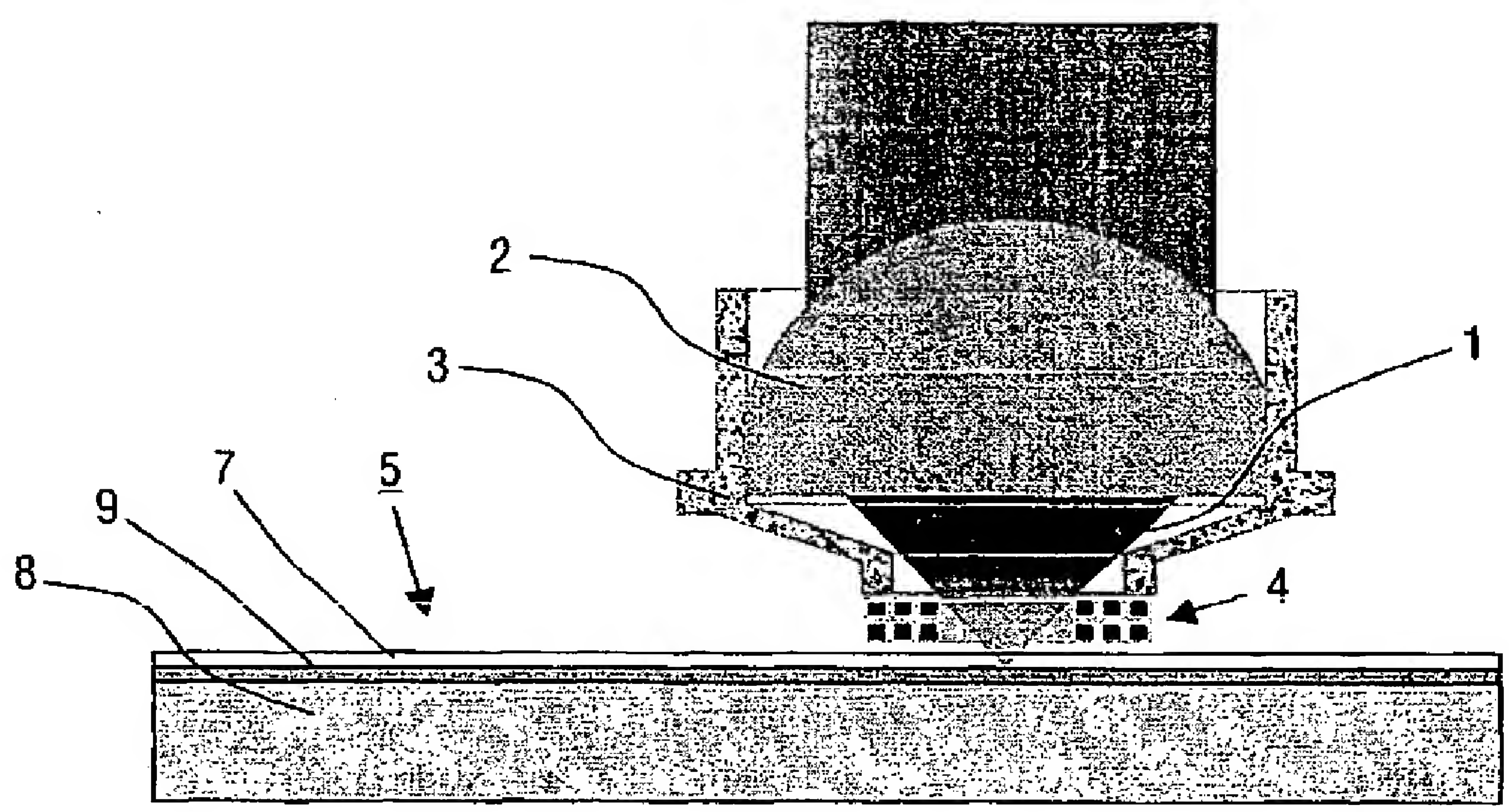
(81) **Designated States** *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) **Designated States** *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM),

[Continued on next page]

(54) **Title:** OPTICAL RECORDING AND READING SYSTEM, OPTICAL DATA STORAGE MEDIUM AND USE OF SUCH MEDIUM



(57) **Abstract:** An optical recording and reading system for use with an optical data storage medium (5) is described. The system comprises the medium (5) having a recording stack (9) and a cover stack (7) that is transparent to a focused radiation beam (1) which has a wavelength λ in air. The cover stack (7) has a thickness dT. The recording stack (9) and cover stack (7) are formed sequentially on a substrate (8). An optical head (3), with an objective (2) having a numerical aperture NA and from which objective (2) the focused radiation beam (1) emanates during recording, is adapted for recording/reading at a free working distance dF of smaller than 50 μm from an outermost surface of said medium (5) and arranged on the cover stack (7) side of said optical data storage medium (5). When dT is smaller than 50? reliable recording and reading is achieved, especially because focus servo problems are prevented.

WO 2004/008441 A2

European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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Published:

— *without international search report and to be republished upon receipt of that report*

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Optical recording and reading system, optical data storage medium and use of such medium

The invention relates to an optical recording and reading system for use with an optical data storage medium, said system comprising:

- the medium having a recording stack and having a cover stack that is transparent to a focused radiation beam with a wavelength λ, said cover stack having a thickness d_T, said recording stack and cover stack formed sequentially on a substrate,

- an optical head, with an objective having a numerical aperture NA and from which objective the focused radiation beam emanates during recording, and adapted for recording/reading at a free working distance d_F of smaller than 50 μm from an outermost surface of said medium and arranged on the cover stack side of said optical data storage medium.

The invention further relates to an optical data storage medium having a recording stack and having a cover stack that is transparent to a focused radiation beam with a wavelength λ, said cover stack having a thickness d_T, the recording stack and the cover stack formed sequentially on a substrate.

The invention further relates to the use of such a medium in such a system.

An embodiment of a system of the type mentioned in the opening paragraph is known from European Patent Application EP 0878793 A2.

An optical data storage medium in such a system may include a transparent substrate having a thickness between 0.6 to 1.2 mm. Such medium, e.g. a magneto-optical disk, may further include a transparent dielectric film which may be formed from silicon nitride, aluminum nitride, silicon oxide and/or ZnS by a so-called sputtering or a vacuum depositing operation on a surface of the transparent substrate. Magneto optical recording layers including amorphous rare earth metal magnetic films such as TbFeCo, GdFeCo, DyFeCo or TbFeCoCr, or perpendicular recording films such as PtCo which may be recorded or formed by a sputtering or vacuum depositing operations; an Al-based metal reflective film mainly composed of Al, AlTi or AlCr which may be formed by a sputtering or vacuum depositing operation; and a transparent protective layer of a UV- curable resin which may be

formed by a so-called spin coating operation.

To record information in the above-mentioned magneto optical recording medium, light is radiated from an optical head through the transparent substrate having a thickness between 0.6 to 1.2 mm to the recording stack so as to heat the layers to a recording temperature. At the same time, a magnetic field is applied by a magnetic head from the opposite side of the transparent substrate. Such magnetic field may be modulated with the information by use of a magnetic field modulation device As a result, the information may be recorded on the recording medium. To reproduce the information from the magneto optical recording medium, light is also radiated by the optical system through the transparent substrate. In this situation, the optical head is arranged on the transparent substrate side of the disk.

In these 4th generation optical systems the numerical aperture (NA) of the objective is larger than 0.80 in order to improve recording density, i.e. spot size of the focused radiation beam. Despite this tendency of the objective to increase in size (NA), however, the increasing demand for high data rate and access time forces the total mass of the objective to shrink. This can only be accomplished if the focal length and hence the free working distance (FWD) is reduced. However if the FWD is reduced the thickness of the transparent substrate, through which the focused radiation beam passes, needs to be reduced. Furthermore, if the NA is increased, then the allowance of the angle by which the medium surface is deviated from the perpendicular with respect to an optical axis of the optical system (tilt angle) is reduced under the effect of double refraction or aberration due to the thickness of the transparent substrate. Thus reduction of the effect of the tilt angle at high NA is another reason to decrease the thickness of the transparent substrate. This transparent substrate with reduced thickness is also called cover layer or more generally cover stack. Thus the purpose of the relatively thin cover layer in 4th generation optical recording is mainly to protect the recording stack from damage and to enable a low FWD.

Another argument for a small free working distance is the size of the coil in case of a magneto-optical data storage medium. If one wants a system with a high data rate, a large bandwidth to modulate the current through the coil is required. For data rates in the order of 100 - 200 Mbit/sec, the switching frequency of the current through the coil must be at least 1-2 GHz, in order to define sharp flanks in the switching behavior of the field. This requires a coil with a small self inductance low resistance an small parasitic capacitance. Apart from the speed of the coil, the power consumption by the coil is also an issue. Therefore it is preferable to use a small coil with a small inner diameter, e.g. smaller than 100

μm. The use of a bigger coil would compromises the data rate and energy efficiency because bigger coils have a larger inductance and a higher power consumption. The closer the coil is brought to the surface, the more energy efficient the magnetic field at the data storage medium can be modulated. However, a magnetic field in the order of 15 kA/m per Ampere of such a small coil penetrates only a few tens of microns into space, so the coil must be kept close to the recording stack and a cover layer that is thicker than e.g.100 μm prevents this. The known system from EP 0878793 A2 has a cover layer thickness smaller than 100 μm. Applicants have found that such relatively thick cover layers, e.g. 50 μm or 25 μm may cause an unreliable recording and read out of data. It may occur that the optical head focuses on the outer surface of the cover layer in which data recording and read out is impossible after which event the optical head needs to refocus onto a subsequent surface. This procedure may lead to interruption of data streams and therefore unreliable data recording and reading. Furthermore, relatively thick covers requires the magnetic coil to have a relatively large magnetic field distance range in axial direction of the coil, which limits the switching speed of the coil and thus the recording reliability at larger data rates.

It is an object of the invention to provide a system of the kind as described in the opening paragraph, which performs reliable recording and readout of data in the recording stack.

It is a second object of the invention to provide an optical data storage medium for reliable recording and readout of data for use in a system of the kind as described in the opening paragraph.

These objects are achieved in accordance with the invention by an optical recording and reading system which is characterized in that d_T is smaller than 50λ. An important feature of the choice of the thickness d_T is the robustness of the focus actuation system. If a medium with a cover stack, i.e. 1 or more layers, of around 20 μm or larger is used, the focus error curve of the system has two zero crossings, with might cause the focus servo to lock onto the surface of the cover stack instead of onto the recording stack. The extra zero crossing is shown in figure 3 by the curve 33. However, when a thinner cover stack is used, the focus error curve does not show an extra zero crossing, so if this type of thin cover stack medium is used, the event of a wrong lock of the focus servo is prevented. The focus error curve of a medium with a relatively thin cover stack is shown in figure 3 by curve 31.

Because of this focus servo issue it is better to choose a thin cover stack. It is advantageous to use a relatively hard cover stack in order to prevent damage of the cover stack.

An additional advantage of such a thin cover stack is that the magnetic coil can be brought close enough to the recording stack in order to generate sufficient magnetic field in the recording stack.

It further has been found that during recording contamination from the medium may evaporate and condense onto the optics of the optical head. The contamination may e.g. be water mixed with small quantities of other contaminants. The water including other contaminants is probably present as a thin (mono)layer on the outer surface of the medium. When no cover stack is present the thin (mono)layer is present very close to the recording stack and is indirectly heated by the recording stack, evaporates and subsequently condenses onto the objective including the other contaminants. This occurs relatively rapidly, i.e. within half an hour (but possibly after seconds), causes unreliable recording and reading of the system and finally may lead to total recording and reading failure. An additional advantage of the application of the relatively thin cover is the prevention of the build-up of contamination onto the objective. This is because the cover layer forms an effective barrier which prevents the thin monolayer on the medium to be heated and evaporated. It was found that no harmful effect, i.e. evaporation, occurs at a relatively thin cover stack thickness of $0.5 - 1$ μm or more. This can be calculated by thermally modeling the heating process by the radiation beam of the recording stack between the substrate and the cover stack (see Fig.5).

In an embodiment the optical head further comprises a magnetic coil arranged at a side of the optical head closest to the cover stack such that an optical axis of the optical head traverses the center of the magnetic coil and the recording stack of the optical data storage medium is of the magneto-optic type. In this case reliable magneto optical recording is possible at a high density and data rate because a high NA, i.e. a small spot, is possible and the magnetic coil may be brought close to the recording stack in which case a magnetic field may be modulated in an energy efficient way.

It is especially advantageous when the magnetic coil has an inner diameter of smaller than 60 μm. The use of a bigger coil would compromise the data rate and energy efficiency because bigger coils have a large inductance and higher power consumption.

In an embodiment of the optical data storage medium the range of d_T is set in dependency of NA and λ (in μm) according to the formula: $d_T < 10\lambda/NA$ μm. The exact thickness range which is optimal depends on the specificities of the optical system, such as the NA of the objective lens and the wavelength of the radiation beam. The NA of thin cover

stack optical data storage media typically is larger than 0.80. Preferably d_T is larger than a thickness d_{Tmin} being a thickness where optical interference effects of the focused radiation beam in the cover stack just start having a negative effect on the reliability of recording and reading of data during recording. The thickness d_{Tmin} is proportional to the so-called confocal parameter: λ/NA^2.

In another embodiment of the optical data storage medium an additional anti reflection stack is present adjacent the cover stack at a side most remote from the substrate. This has the advantage that less radiation beam energy is lost at the outer surface of the medium. Furthermore the strength of the focus error signal coming from the outer surface is substantially reduced and therefore locking onto the outer surface layer instead of on the recording stack is less likely. Preferably the anti reflection stack comprises layers selected from the group TaO_2, SiO_2, SiN and MgF_2.

The invention will be elucidated in greater detail by means of exemplary embodiments and with reference to the accompanying drawings, in which

Figure 1A shows an embodiment of the system according to the invention with small free working distance optics used in an MO drive,

Figure 1B shows the structure of the layer stack of the medium of Fig.1A,

Figure 2 shows the magnetic field strength as function of distance to the magnetic coil,

Figure 3 shows focus error curves at different cover stack thicknesses,

Figure 4A shows the optical surface of the objective of the optical head before first recording and,

Figure 4B shows the optical surface after contamination build-up.

Figure 5 shows modeling results of the temperature profile in z direction with and without cover layer.

In Fig. 1A and 1B, an embodiment is shown of an optical recording and reading system for use with an optical data storage medium 5. The medium 5 comprises a recording stack 9 and has a cover stack 7 that is transparent to a focused radiation beam 1. The wavelength λ of the radiation beam 1 is 405 nm. The cover stack 7 has a thickness d_T = 3.180 μm. Said recording stack 9 and cover stack 7 are formed sequentially on a substrate 8

e.g. by sputtering. An optical head 3, with an objective 2, having a numerical aperture NA = 0.85, from which the focused radiation beam 1 emanates during recording is present at the cover stack 7 side of said optical data storage medium 5. The optical head 3 is adapted for recording/reading at a free working distance d_F = 15 μm from the outermost surface of the medium 5. An additional anti reflection stack 11 is present in the cover stack 7 at a position most remote from the substrate 8. The anti reflection stack 11 comprises layers selected from TaO_2, SiO_2, SiN and MgF_2. The latter is less robust than the former three. A suitable cover stack design, in this order, e.g. is:

Design 1

(-Substrate 8)

(-Recording stack 9)

-3 μm UV curable resin or plastic PSA sheet 10 (refractive index n=1.52)

-11 nm TaO_2 (n=2.35)

-21.6 nm SiO_2 (n = 1.46)

-79 nm TaO_2

-68 nm SiO_2.

An alternative is:

Design 2

(-Substrate 8)

(-Recording stack 9)

-3 μm UV curable resin or plastic PSA sheet 10

-17.7 nm SiN (n = 2.04)

-23.1 nm SiO_2

-86 nm SiN

-68.8 nm SiO_2.

Note that in design 1 and 2 the anti reflection stack 11 comprises 4 layers and is especially suitable when the outer portion of the radiation beam is incident substantially non-perpendicularly, e.g. 60- 70 degrees, when a high NA of e.g. 0.90 is used.

Another alternative is:

Design 3

(-Substrate 8)

(-Recording stack 9)

-3 μm UV curable resin or plastic PSA sheet 10

-75.4 nm TaO_2 (n = 2.04)

-48.4 nm SiO_2

In design 3 the anti reflection stack 11 comprises 2 layers and is especially suitable when a relatively low NA of e.g. < 0.50 is used.

The cover stack 7 can be applied by techniques such as spin- or dip coating, vapor deposition and usage of a plastic foil/adhesive combination, e.g. a pressure sensitive adhesive (PSA).

The optical head 3 further comprises a magnetic coil 4 arranged at a side of the optical head 3 closest to the cover stack 7. An optical axis of the optical head 3 traverses the center of the magnetic coil 4 and the recording stack 9 of the optical data storage medium 5 is of the magneto-optic type. The recording stack 9 may e.g. include, in this order, a reflective metal layer as known in the art e.g. Al, other auxiliary layers, a 50 nm layer of the magnetic material GdFeCo and a 35 nm interference layer of SiN or ZnS/ SiO_2. The use of TbFeCo as magnetic material instead of GdFeCo gives similar results. When the medium 5 does not have a cover stack 7 contamination will build up(see Fig 4) in a matter of minutes resulting in servo, e.g. focus or tracking failure. Reliable recording and reading occurs because the cover stack is relatively thin and no double zero crossing in the focus error curve is present (see Fig.3). The system proves to be stable and robust. When a cover stack 7 according to the invention is present contamination build-up on the objective could not be observed.

In Fig. 2 a plot is shown of the strength of the magnetic field at an axial distance from the magnetic coil. This plot clarifies why the range of working distance is only a few tens of microns for a typical high speed coil.

In Fig. 3 three focus error curves 31, 32 and 33 are shown. Curve 31 (solid) corresponds to a 4 μm, curve 32 (dash-dot) to a 8 μm and curve 33 (dashed) to a 25 μm cover stack 11 thickness. Note the extra zero crossing when the cover is around 25 μm. The vertical lines indicate the position of the focal point in each case.

Fig. 4A shows the optical surface of the objective 3 when is it still clean and Fig. 4B shows the surface after contamination build-up due to redeposition of evaporated contamination of a medium which does not contain a cover stack 7. Application of a cover stack solves the problem of contamination build-up.

In Fig. 5 thermal modeling result are presented. The temperature is normalized to 1 in the recording stack. The solid curve, which corresponds to the temperature profile including a cover layer (stack) 7, shows a rapid decay of temperature in just half a μm. From this it may be deduced that effective thermal insulation already is achieved at a cover thickness of a half a μm or more.

It should be noted that the above-mentioned embodiments illustrate rather than limit the invention, and that those skilled in the art will be able to design many alternative embodiments without departing from the scope of the appended claims. In the claims, any reference signs placed between parentheses shall not be construed as limiting the claim. The word "comprising" does not exclude the presence of elements or steps other than those listed in a claim. The word "a" or "an" preceding an element does not exclude the presence of a plurality of such elements. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

According to the invention an optical recording and reading system for use with an optical data storage medium is described. The system comprises the medium having a recording stack and a cover stack that is transparent to a focused radiation beam which has a wavelength λ in air. The cover stack has a thickness d_T. The recording stack and cover stack are formed sequentially on a substrate. An optical head, with an objective having a numerical aperture NA and from which objective the focused radiation beam emanates during recording, is adapted for recording/reading at a free working distance d_F of smaller than 50 μm from an outermost surface of said medium and arranged on the cover stack side of said optical data storage medium. When d_T is smaller than 50λ reliable recording and reading is achieved, especially because focus servo problems are prevented.

CLAIMS:

1. An optical recording and reading system for use with an optical data storage medium, said system comprising:

- the medium having a recording stack and having a cover stack that is transparent to a focused radiation beam with a wavelength λ in air, said cover stack having a thickness d_T, said recording stack and cover stack formed sequentially on a substrate,

- an optical head, with an objective having a numerical aperture NA and from which objective the focused radiation beam emanates during recording, and adapted for recording/reading at a free working distance d_F of smaller than 50 μm from an outermost surface of said medium and arranged on the cover stack side of said optical data storage medium, characterized in that d_T is smaller than 50λ.

2. A system according to claim 1, wherein the optical head further comprises a magnetic coil arranged at a side of the optical head closest to the cover stack such that an optical axis of the optical head traverses the center of the magnetic coil and the recording stack of the optical data storage medium is of the magneto-optical type.

3. A system according to claim 2, wherein the magnetic coil has an inner diameter smaller than 60 μm.

4. A system according to any one of claims 1 - 3, wherein the range of d_T is set in dependency of NA according to the formula: $d_T < 10\lambda/NA$ μm.

5. An optical data storage medium having a recording stack and having a cover stack that is transparent to a focused radiation beam with a wavelength λ, said cover stack having a thickness d_T, the recording stack and the cover stack formed sequentially on a substrate, characterized in that d_T is smaller than 50λ μm.

6. An optical data storage medium according to claim 5, wherein the range of d_T is set in dependency of NA and λ according to the formula: $d_T < 10\lambda/NA$ μm.

7. An optical data storage medium according to claim 6, wherein d_T is larger than a thickness d_{Tmin} being a thickness where optical interference effects of the focused radiation beam in the cover stack just start having a negative effect on the reliability of recording and reading of data during recording.

8. An optical data storage medium according to claim 5, wherein an additional anti reflection stack is present in the cover stack at a position most remote from the substrate.

9. An optical data storage medium according to claim 8, wherein the anti reflection stack comprises layers selected from the group TaO_2, SiO_2, SiN and MgF_2.

10. Use of an optical data storage medium according to anyone of Claims 5 – 9 for reliable recording and reading in a system as claimed in anyone of Claims 1-4.

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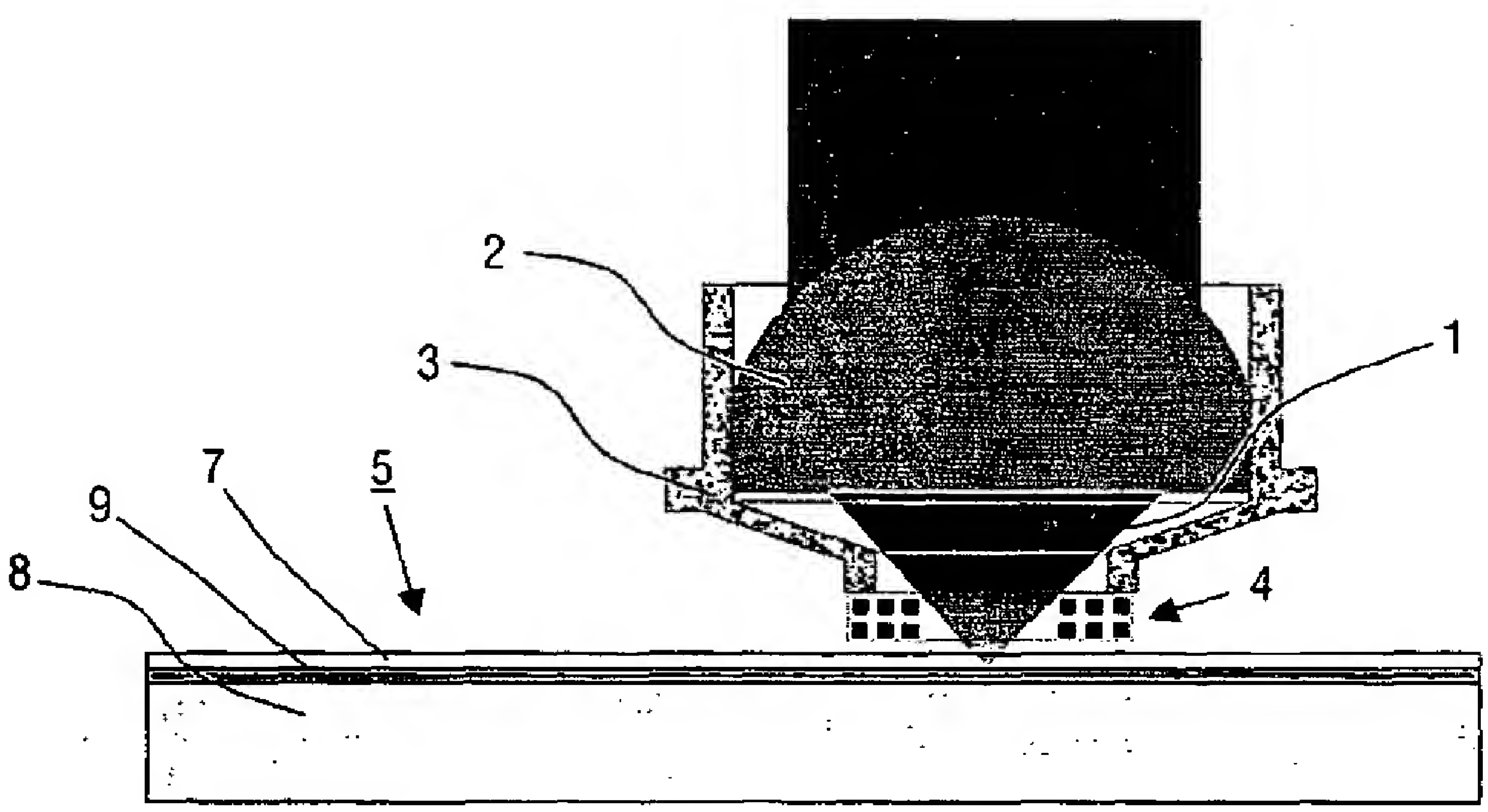
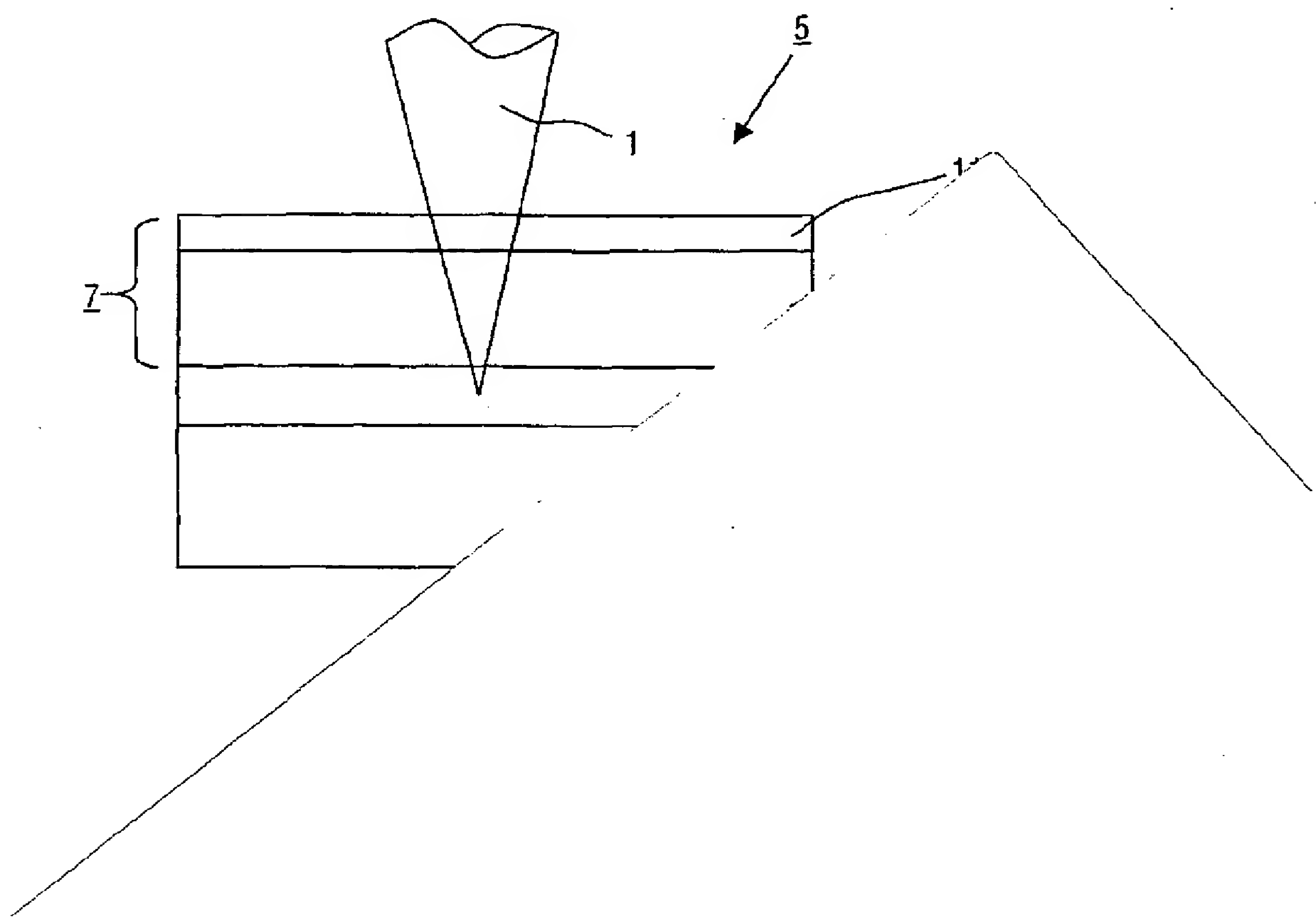


FIG.1A



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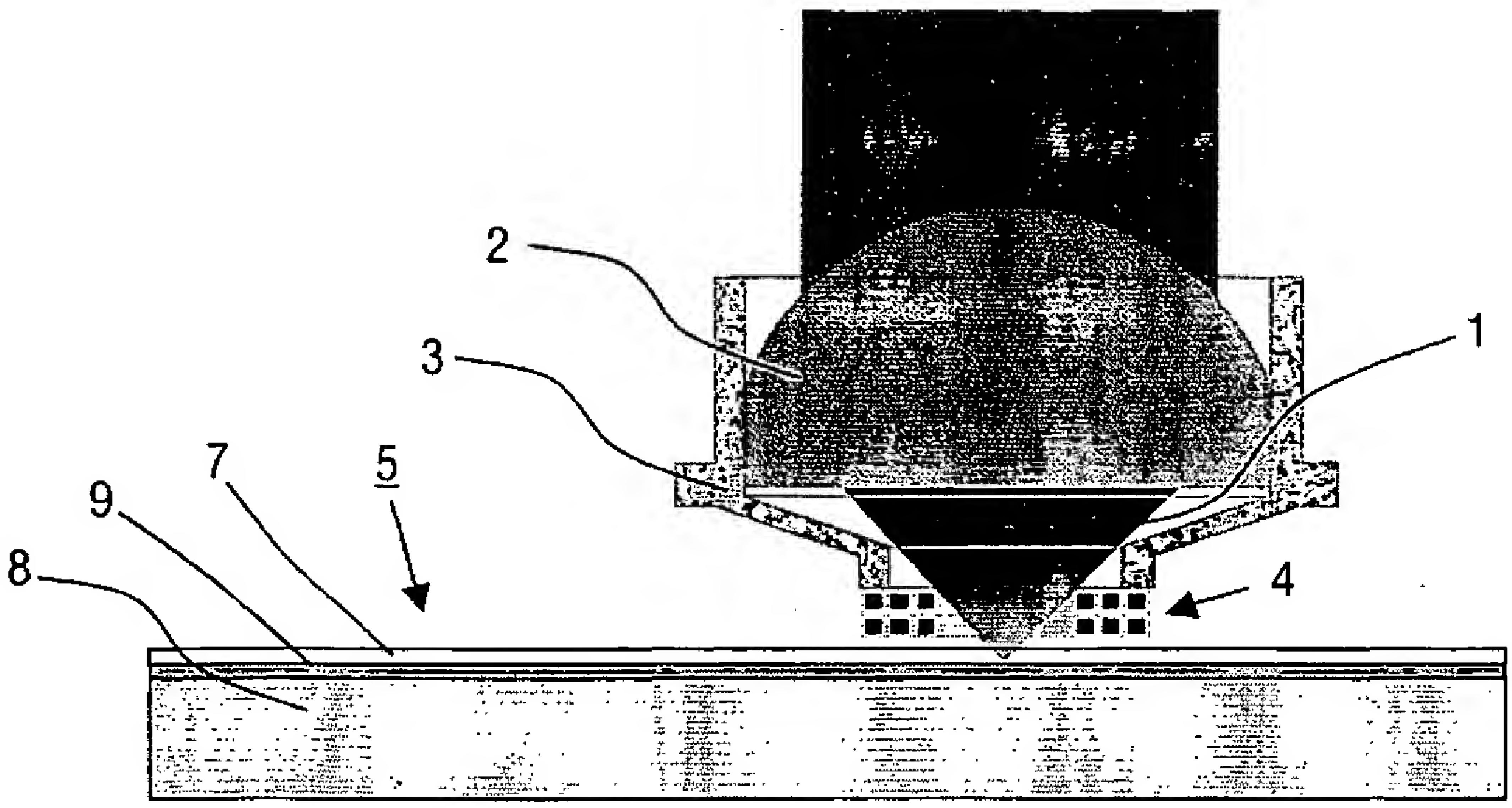

FIG.1A

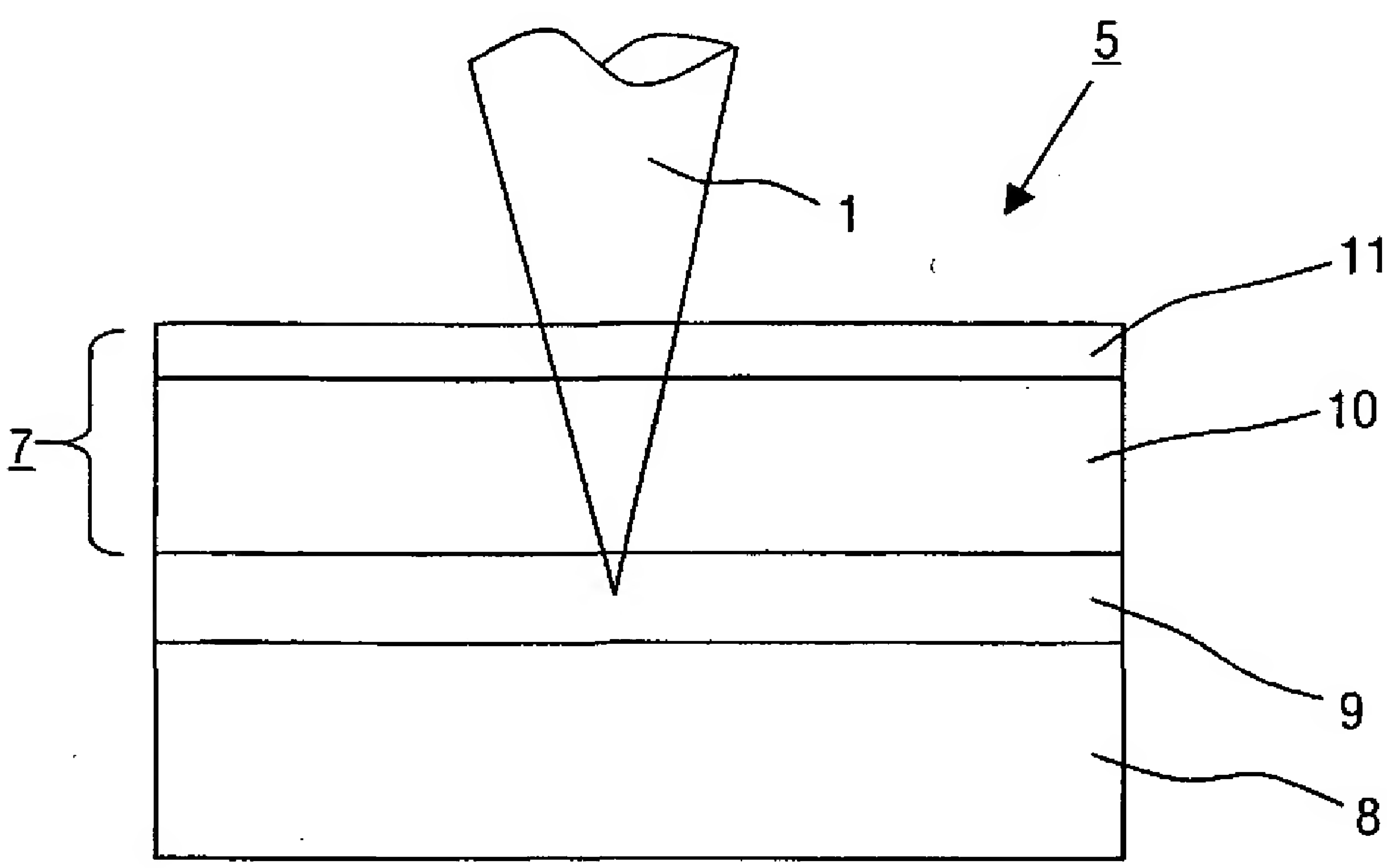

FIG.1B

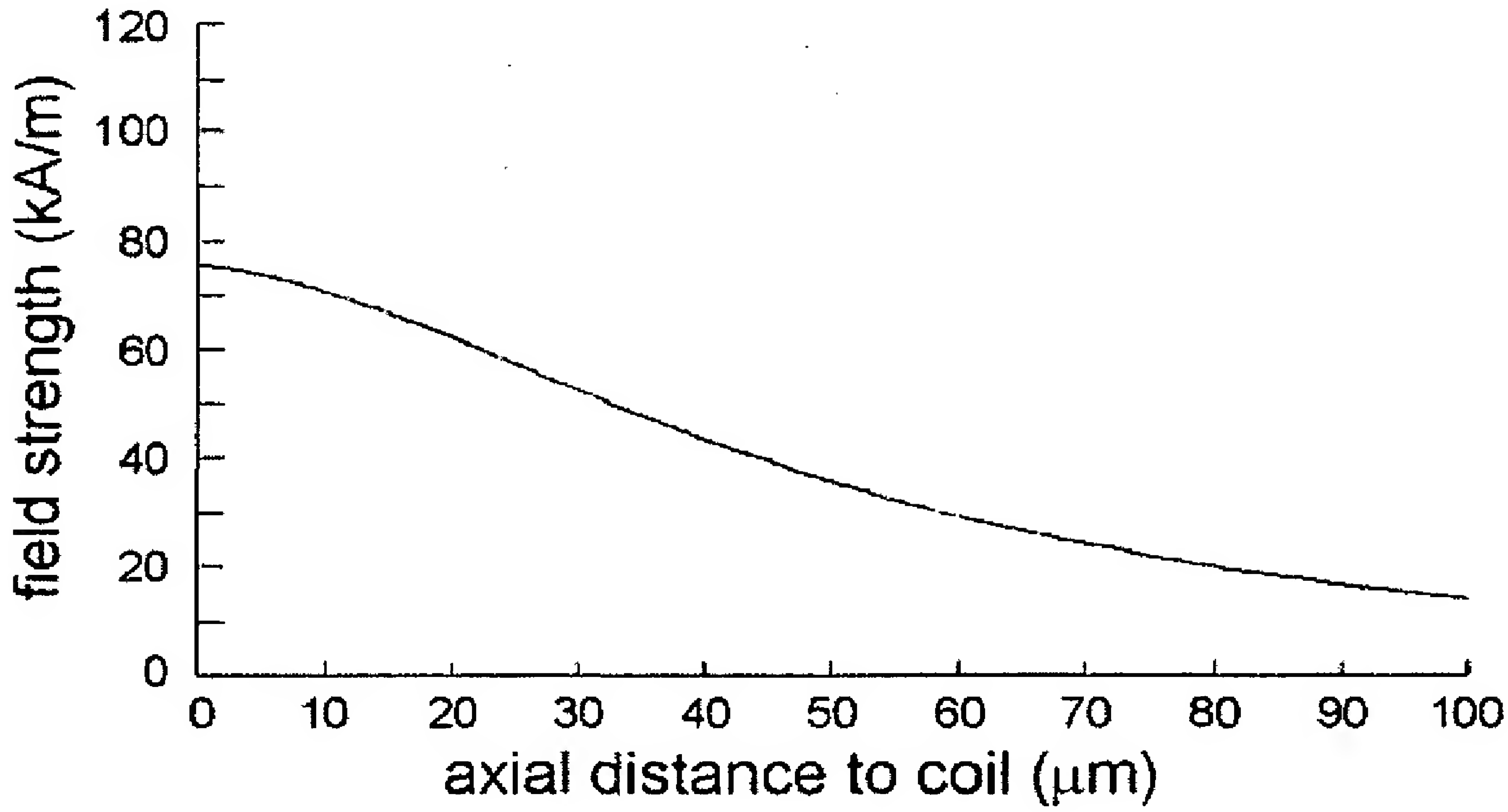
field strength (kA/m)
0
20
40
60
80
100
120
0
10
20
30
40
50
60
70
80
90
100
axial distance to coil (μm)

FIG.2

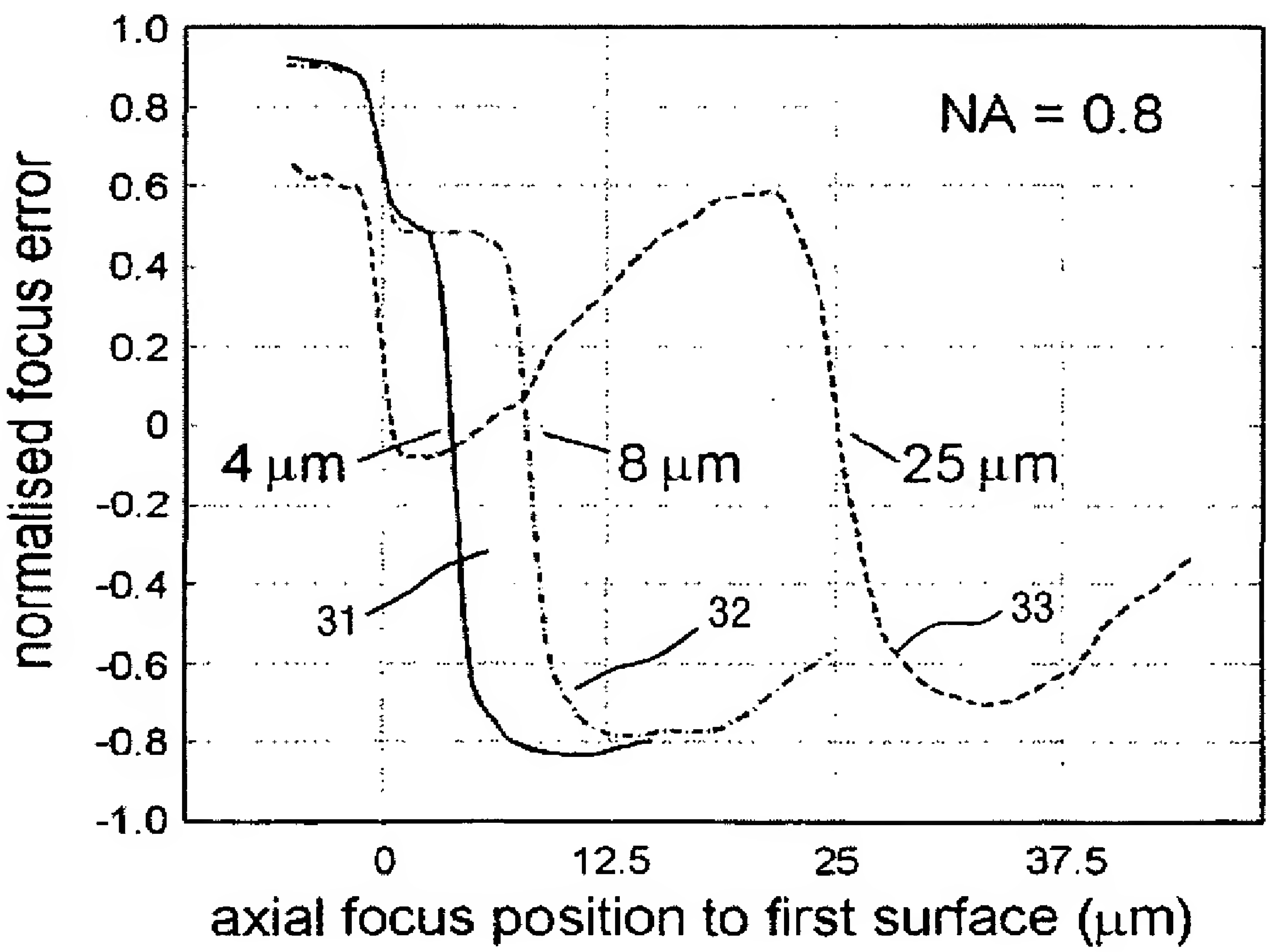
normalised focus error
1.0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
NA = 0.8
4 μm
8 μm
25 μm
31
32
33
0
12.5
25
37.5
axial focus position to first surface (μm)

FIG.3

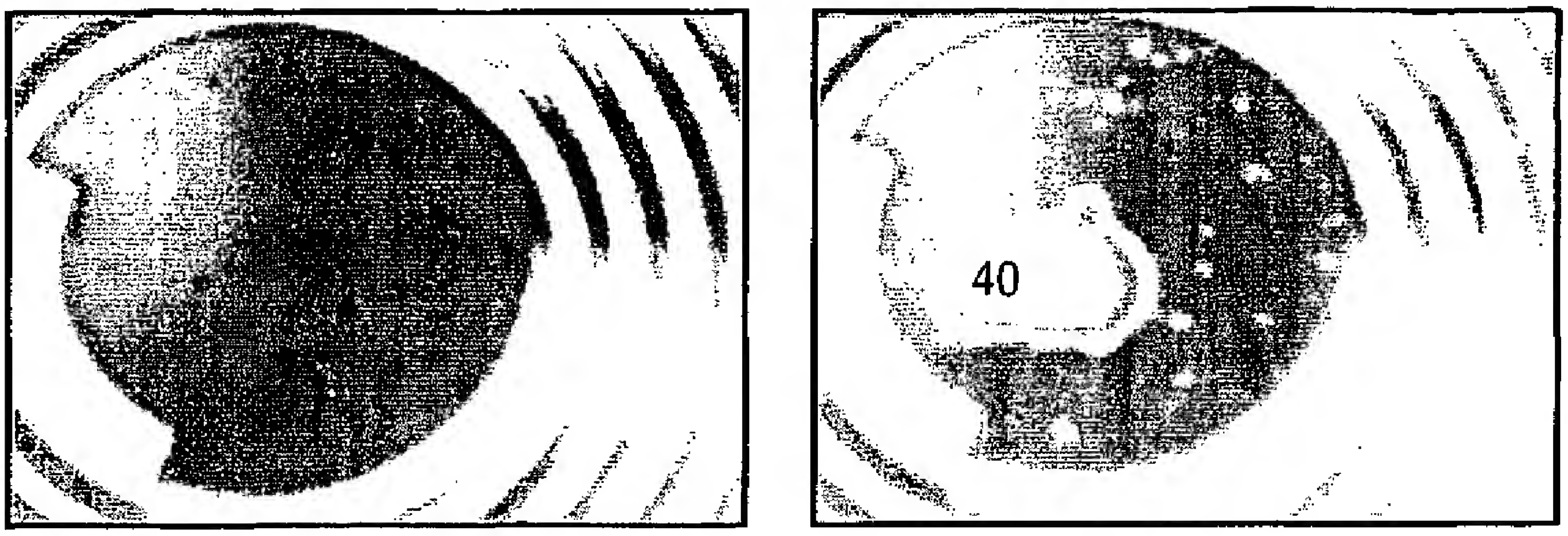

FIG.4A FIG.4B

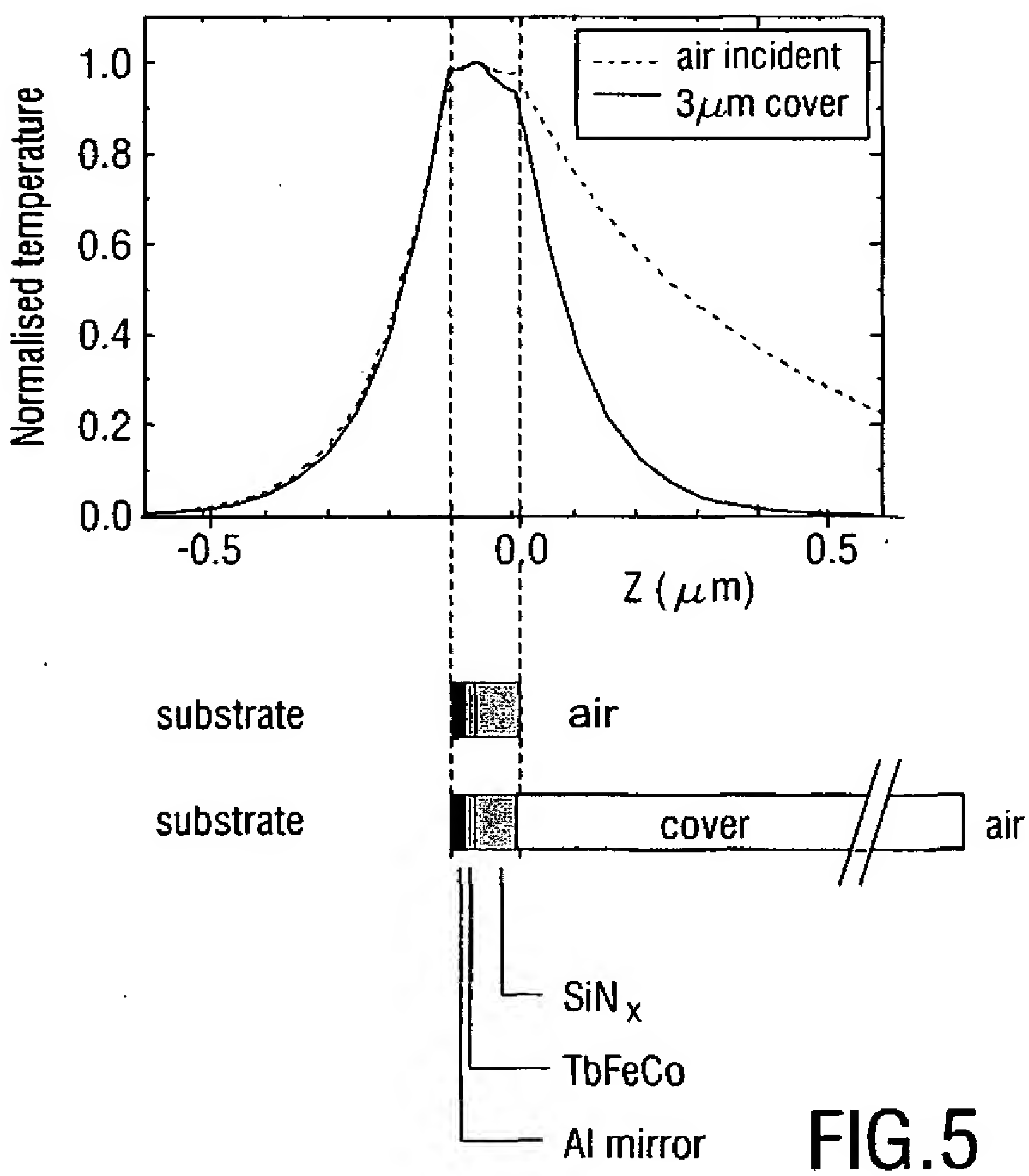

FIG.5